JOINT PAINT REMOVAL STUDY

JOINT POLICY COORDINATING GROUP ON DEPOT MAINTENANCE
TASKING DIRECTIVE 1-90

FINAL REPORT FOR

SODIUM BICARBONATE PAINT STRIPPING

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FOREWORD

This is the final report for the sodium bicarbonate paint stripping process, validation, and material characterization. It is one of five individual studies directed by the Joint Policy Coordinating Group on Depot Maintenance, Tasking Directive 1-90.

This program evaluated paint stripping based on sodium bicarbonate as the stripping media. The validation efforts described herein were done by the Air Force and Marine Corps for use on various aircraft, ground vehicles, and/or components. The goals of this program were to determine if this process could meet or exceed criteria for productivity versus possible blast-imparted substrate damage and to evaluate the potential corrosive qualities of the media.

Points of contact for the Joint Paint Removal Study are in Appendix VI.

EXECUTIVE SUMMARY

BACKGROUND:

The Joint Policy Coordinating Group on Depot Maintenance (JPCG-DM) tasked the Joint Technology Exchange Group (JTEG) to conduct a study of alternative paint removal processes that have potential use within the DOD depot maintenance community. Tasking directive 1-90 was signed by the JPCG-DM on 19 Dec 89 (Appendix I). The JTEG was directed to plan and manage the study, identify techniques to be studied, sponsor/advocate research and development initiatives, oversee joint Service testing, evaluate the study, and report the results.

OBJECTIVE:

The objective of the study is to give managers coordinated joint Service technical and management information to help them make investment and application decisions regarding current and emerging paint removal processes. The study identified and evaluated alternative paint removal processes. It also helped eliminate duplicate developmental and test efforts.

SCOPE:

To realize the quickest benefits, five paint removal processes were studied: plastic media blasting, laser, sodium bicarbonate blasting, carbon dioxide pellet blasting, and high pressure water blasting. To reduce costs and time frames, tests were conducted at facilities that had already established or begun efforts to establish organic capability.

STUDY PLAN:

The study consisted of three phases.

Phase I was a comprehensive review, within DOD, to identify existing capabilities/plans and to establish a baseline for the study. The baseline, which related to the five alternatives, identified current capabilities, the degree of maturity for each method, developmental efforts and time frames, and study criteria. Also, from the baseline data, lead activities were recommended and study teams established.

Phase II is the feasibility study, testing, and analysis phase, which began by designating lead activities and developing a coordinated plan for each process to include economic, environmental, and technical evaluations. During Phase II, the status of each alternative process was reported periodically to the JPCG-DM and the depot maintenance community.

Phase III involves analysis and documentation of a process. For each process, an interim report will be provided as testing is completed. Following the completion of all sub-studies, a final report will provide a comparative analysis.

SUMMARY FOR SODIUM BICARBONATE BLASTING - VALIDATION AND MATERIAL CHARACTERIZATION

This program evaluated a paint stripping process based on sodium bicarbonate blasting by the Air Force and Marine Corps for use on various aircraft, ground vehicles and/or components. The goal of this program was to determine if this particular process could meet or exceed criteria for productivity versus possible blast-imparted substrate damage.

The Air Force and Marine Corps used "ARMEX" blast media in the "Accustrip" blasting system, developed by Schmidt Manufacturing Inc. The Marine Corps also tested the "Aqua Miser", developed by Carolina Equipment Supply, and the "Jet Stripper", developed by WhiteMetal Inc. The Accustrip process pneumatically propels the blast medium to remove paint and injects water primarily for dust control during blasting. The Aqua Miser and Jet Stripper use water at high pressure to remove the paint and sodium bicarbonate may be injected to increase the aggressiveness of the blast. Additional information on the blasting systems is presented in Appendix II.

The Air Force test program assessed degradation of baseline fatigue life and crack growth rate, cladding erosion, excessive blast-induced residual stress, and increase of substrate surface roughness. Substrate materials used for the program were typical aerospace materials; i.e., bare and clad 2024-T3 and 7075-T6 aluminum alloys. Test materials were prepared with MIL-P-23377 epoxy primer and MIL-C-83286 polyurethane topcoat per specifications found in Technical Order (T.O.) 1-1-8. Test panels were subjected to an elevated temperature cure of 210 degrees F for 96 hours following a 7-day room temperature cure cycle to artificially age the topcoat system.

The program evaluation indicates that the Accustrip blasting system, at the process parameters developed, shows minimal blast-imparted substrate damage. However, the process does erode the cladding on the aluminum alloy at a high rate. The production rate (paint stripping) associated with the parameters was 0.3 ft^2/minute, which falls below the nominal Air Force goal of 0.5 ft^2/minute.

Accustrip's production rate coupled with its tendency to erode aluminum cladding excludes the process from general Air Force use. However, the Air Force still may realize the benefits of a more environmentally friendly depainting system by increasing the production rate with more aggressive process parameters, and by limiting its use of the Accustrip to components the process would not be degraded.

Damage criteria observed in the Marine Corps test program was related to serviceability after stripping. The processes were used on steel, aluminum, fiberglass, and glass. Heavy iron and thick aluminum were checked for warping or alteration, and border materials were checked for damage.

The Marine Corps mainly tested production items, vehicles, and components, to determine the strip rate and effectiveness of each process. No damage was observed on the base materials or adjacent structures. Border materials such as rubber gaskets, fiberglass, and glass were not damaged, however a potential exist for operators to induce damage by dwelling too long in one area.

The Marine Corps has purchased the Accustrip blasting system and is considering putting it in a booth in its new blasting/cleaning facility at MCLB Albany, GA.

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SECTION I - OVERVIEW OF SODIUM BICARBONATE BLASTING

1.1 INTRODUCTION

1.1.1 The first large-scale use of sodium bicarbonate for stripping coatings from soft metal occurred during the Statue of Liberty Centennial Restoration. Part of the project involved removing many layers of paint and sealant from the statue's interior skin. Workers handled most layers with a liquid nitrogen spray. But, the oldest layer, the one next to the copper skin, was a coal-tar sealant that posed a serious problem. The coal tar had to be removed without damaging or thinning Liberty's copper skin. After unsuccessfully trying several blasting media, the coatings contractor evaluated a blast spray formula containing sodium bicarbonate. The grit was hard enough to remove the coal tar but soft enough not to harm the copper. Sodium bicarbonate's ability to do the job smoothly and efficiently without adversely affecting the workers or the statue made it a promising candidate for future industrial use in related applications.

1.1.2 A preliminary demonstration of the new abrasive paint stripping process received a cursory evaluation at Kelly AFB in the fall of 1988. The potential utility of the process was proven when workers at Kelly AFB stripped the outer skin of a TF-102 aircraft. Paint thickness on this aircraft was 3 to 7 mils and the blasting time was 10.9 hours. Total processing time, including setup and cleaning, was 56 hours. Additionally, blasting tests were conducted on some composite materials. Although casual observations of the blasted material revealed no significant immediate damage, the long-term impact or the corrosion aspects of the blasted material was not determined. A preliminary cost evaluation for the process showed it would be economically competitive with chemical stripping. However, to find the financial attractiveness of the process, a detailed economic analysis was required. The proposed cost analysis would be compared with the data obtained from the plastic media blasting (PMB) process.

1.2 GENERAL DESCRIPTION OF SODIUM BICARBONATE BLASTING

Sodium bicarbonate is a soft blast media with a heavier specific gravity and less hardness than most plastic abrasive. Sodium bicarbonate blasting systems are similar to conventional air blast systems. The main differences are in the addition of a water supply and pump for the sodium bicarbonate system with an injection head for injecting water into the air stream behind a standard blast nozzle.

1.3 APPLICATIONS

1.3.1 Sodium bicarbonate is a white, crystalline material made by the action of carbon dioxide gas on sodium carbonate solutions. Its most important commercial applications are:

- In the food industry as a leavening ingredient.
- In the pharmaceutical industry as an effervescent agent.

- A neutralizing agent.
- A mild abrasive (dental applications).
- As an antacid ingredient.
- In agriculture as a rumen buffer; 7) in environmental applications such as sewage treatment plants.
- In potable water systems and swimming pools as a buffer and source of alkalinity.
- In flue gas desulphurization as an acid neutralizing and scavenging agent.

1.3.2 Sodium bicarbonate has a broad range of stripping and cleaning applications for the private and commercial sector, and the military Services. The media is nontoxic, nonflammable, and works well on all military coating systems. Sodium bicarbonate processes that have been developed can be controlled to remove paint and to leave the smooth residual primer on composite panels. Since the media gets used only once, then discarded, no recovery or recycling systems are necessary. Also, since food grade material is used, heavy particle contamination is not a problem.

1.3.3 Because of its soft abrasive qualities, sodium bicarbonate (baking soda) has long been known for its use in the home as a scouring agent. More recently, dentists have been using a prophylactic powder to clean teeth and electronic parts manufacturers have been using a variation of this powder to deflash circuit boards and finish components. The military Services are using sodium bicarbonate blasting processes to clean and strip a variety of weapon systems and components. The process is well suited to applications that use limited equipment, such as operational maintenance units, field deployable maintenance groups, and especially to augment work in existing maintenance facilities with a limited workload.

1.4 MARINE CORPS TEST PROGRAM

1.4.1 The Marine Corps test program was planned with its "inspect, repair only as necessary" (IROAN) procedures. The Marines tested production items to find the rate and effectiveness of the sodium bicarbonate process to remove paint. Since their equipment may go through the IROAN process several times before being completely rebuilt, the blasting process may have to remove several layers of primer and top coats before completely stripping the equipment. Therefore, for control purposes, test panels also were prepared and stripped.

1.4.2 Results.

1.4.2.1 Effects on material.

1.4.2.1.1 Used on heavy iron or thick aluminum, sodium bicarbonate blasting does not warp, alter, or remove base materials. Additional benefits are: parts are stripped and cleaned at the same time, paint can be removed one layer at a time, and most of the material's pretreatment is removed with the primer coat.

1.4.2.1.2 Border materials consisting of rubber gaskets, fiberglass, and glass are not damaged. However, operators can inflict damage on the border materials during blasting if they dwell too long in one place or blast with the nozzle too close to the material.

1.4.2.1.3 No adverse effects were observed on adjacent structures and no taping/masking is required.

1.4.2.2 Process evaluation.

1.4.2.2.1 Paint was successfully removed from all of the parts/equipment tested. However, most corrosion was not removed. Productivity increases were not noted during the testing and small trials in production work. Paint removal rates for the three systems tested are in the following table:

1 - Accustrip; 2 - Aqua Miser; 3 - Jet Stripper

Vehicle	Material Tested (thickness - inches)	Mils of Paint	Rate of Removal (sq ft/minute) 1	2	3
LAV	.25 steel armor	15	.25	.45	.35
		13	.25	.45	.35
		8	.33	.50	.42
AAV-P7	.75 aluminum	14	.25	.45	.35
5-ton truck	.19 steel	12	.25	.45	.35
	.38 steel	15	.25	.45	.35
	.06 steel	19	.22	.42	.30
HMMWV	.19 fiberglass	8	.33	.50	.42
	.12 aluminum	6	.33	.50	.42
Test panel	.06 steel	4.4	.33	.50	(*1)

(*) No test panel used

1.4.2.2.2 Normal operator fatigue was observed in using sodium bicarbonate blasting systems. Higher-pressure sodium bicarbonate blasting systems were used for two days at a time. Continued use required recommendations from the base safety office. Noise levels were very high during testing, ranging from 112 to 120 decibels (db); therefore, operators are required to wear double hearing protection.

1.4.3 Conclusion.

While sodium bicarbonate blasting systems remove paint slower than methods currently used, the process has favorable attributes. These include the ability to clean parts at the same time they are stripped, to not damage border materials without taping/masking, paint can be removed one layer at a time, and the generated wastes are treated at the industrial waste treatment plant (IWTP).

1.5 AIR FORCE TEST PROGRAM

1.5.1 Rationale.

1.5.1.1 The Air Force has, over the last several years, been actively engaged in researching and developing alternative methods for depainting with the intent of reducing the volume of hazardous materials being treated before being released into the environment. However, finding these methods has been difficult. As a result the Air Force has scrutinized an assortment of blast-based processes for depainting, since these types of processes seem to offer the best solution for now.

1.5.1.2 San Antonio Air Logistics Center (SA-ALC) initiated the Air Force program to evaluate sodium bicarbonate stripping for depainting aircraft and/or aircraft components. Sodium bicarbonate stripping had the potential to be more cost effective than current chemical-based methods. Current methods are labor intensive and expensive because their waste streams have to be treated.

1.5.2 Scope.

The scope of the Air Force program included the installation of a dedicated test facility at SA-ALC. Process optimization and materials conditioning took place at SA-ALC in a contractor-supplied, dedicated test cell. SA-ALC supplied the blast and feed system used for the evaluation.

1.5.3 Objective.

The program objective is to optimize the process and characterize possible effects on typical aircraft metallic materials.

a. Process optimization was conducted to arrive at process parameters that would provide the maximum paint stripping rate with little or no damage to the substrate materials.

b. Production rates were evaluated by testing strip rates on large panels, while possible blast damage was evaluated by a qualitative measure of residual stress.

c. Process parameters derived from the optimization subsequently were used to condition materials used for the materials characterization portion of the program.

d. Materials characterization considered possible blast-imparted changes of fatigue crack growth rate (FCGR), fatigue life, residual stress, cladding erosion, and surface roughness. Baseline tests for 2024-T3 bare aluminum alloy were run for fatigue and FCGR comparisons. Surface roughness tests were conducted on both bare and clad surfaces for 2024-T3 and 7075-T6 alloys. Assessments of cladding erosion were based on 2024-T3 and 7075-T6 clad alloys.

1.5.4 Results.

1.5.4.1 Test data showed the following results at process parameters that had an approximate paint strip rate of 0.3 ft^2/minute:

a. There was no appreciable change in crack growth characteristics at the parameters tested.

b. Mean fatigue life comparisons of the treated notched specimens showed no fatigue life degradation. The fatigue life of the front notch condition showed improvement.

c. At the parameters used for the testing there is a high rate of cladding erosion for both alloys.

d. Roughness initially increases more vigorously with the clad surfaces, then decreases as the cladding is eroded from the substrate.

e. Roughness on bare surfaces peaks at four blast cycles and does not appear to increase.

f. Increased roughness for bare surfaces was not excessive.

1.5.4.2 Production capabilities of sodium bicarbonate blasting were low and were coupled with a proclivity to erode aluminum cladding with no other indications of unacceptable substrate damage.

1.5.5 Conclusions.

The production paint stripping rate of 0.3 ft^2/minute was somewhat lower than the nominal Air Force goal of 0.5 ft^2/minute, and there was excessive erosion of aluminum cladding materials. Both of these characteristics might be improved with further development. However, sodium bicarbonate blasting does have the benefit of replacing chemical strippers, and it could be used effectively for those materials that would not be degraded by cladding erosion.

SECTION II - TEST PROGRAM DESCRIPTIONS

2.1 MARINE CORPS TEST PROGRAM

2.1.1 Marine Corps testing was performed outside in the abrasive blast area. Initial testing began inside but was moved outside because of noise from the blast system. Testing was performed over a span of several months at a temperature range of 40 to 90 degrees Fahrenheit (F). Humidity ranged from 40 to 100 percent. The same operator, a sandblaster (WG-07), did all blasting for the tests.

2.1.2 Criteria set forth by the Marine Corps dictated that the tests be performed in a production environment where the results would have a direct bearing on decisions for the future use of sodium bicarbonate blasting. Tests were structured to determine the rate of paint removal and the effect of sodium bicarbonate blasting on the base material of heavy iron or thick aluminum; on border materials consisting of rubber gaskets, fiberglass, and glass; and on adjacent structures.

2.1.3 The Marine Corps tested the blast media on three types of commercial, off-the-shelf equipment. Two of the systems, Accustrip and Aqua Miser, required air and water hookups. The Jet Stripper required only a water supply. A comparative description of the three systems follows:

Description	Accustrip	Aqua Miser	Jet Stripper
Model	16W	E25	DP-1
Trailer Mounted	Yes	No(*1)	Yes
Size; lxwxh inches	66 x 54 x 64	68 x 36 x 60	103 x 60 x 62
Weight	1210 lbs	1600 lbs	2530 lbs
Media Tank Capacity	6 cubic feet	50 lbs	9 cu ft/450 lbs
Water Tank	40 gallons	none	60 gallons
Blast hose	50 feet	50 feet	50 feet
Water hose	50 feet	50 feet	50 feet
Water Flow rate	0.5 gpm	3 gpm	0.5 gpm
Media Flow rate	60 to 240 lbs/hr	30 to 60 lbs/hr	30 to 60 lbs/hr
Air pressure req	125 psi at 265 cfm min	100 psi at 30 cfm min	125 psi max at 375 cfm min
Pressure ranges	10 to 100 psi	13,500 to 16,000	20 to 90 psi
Pressure at nozzle	20 to 100 psi	14,500 psi	90 psi
Power required	none	70 amp at 480 v, 60 cycle, 3 phase	none
Personnel required	1 each	1 each	1 each
Cost of system	$15,000	$40,000	$40,000

(*1) Aqua Miser is mounted on dollies.

Note: Each manufacturer has more than one model and different variants for each model.

2.2 AIR FORCE TEST PROGRAM

2.2.1 Air Force criteria dictated that sodium bicarbonate blasting be tested in a suitable environment that also could be integrated into the SA-ALC work environment. The program's principal task was validating (if possible) a sodium bicarbonate process as an alternative paint removal method for aircraft parts and components common to work environment. This validation would include characterizing the production and damage potential of the process by preparing and testing controlled materials.

2.2.2 Test Booth.

2.1.2.1 The first task in the program was to design and install a chamber suitable for conducting environmental activities. Spray Booth Systems, Inc., a commercial supplier of paint spray booths, designed, fabricated, and installed the blast booth and modified the facility needed to accommodate the booth.

2.2.2.2 The objective was to provide a chamber suitable for quantitatively testing sodium bicarbonate blasting.

2.2.2.3 Functional requirements established by SA-ALC were:

a. The chamber must be large enough to hold elevator, aileron, or similar panels from the large aircraft maintained at SA-ALC.

b. The chamber must prevent emissions of particulate and vapors containing dissolved sodium bicarbonate to the atmosphere.

c. The chamber must be provided with filtered and cleaned air suitable for personnel breathing.

d. The chamber must be fitted with lights and windows suitable for external observers to watch operations.

2.2.2.4 The following technical requirements were established for the blast booth:

a. Chamber size - 14-ft wide x 14-ft high x 34-ft long.

b. Minimum lighting level - 100 foot-candles at three ft above the floor.

c. Ventilation system - 100 feet per minute (fpm) minimum through the booth, with roof-mounted intake and exhaust fans.

d. Air pollution control - duct work, plenums, pump types, and water wash filters that can remove non-solubilized media and paint particles.

e. Apparatus that can purify 80 cubic feet per minute (cfm) of air at 100 pounds per square inch gauge (psig) for personnel breathing (Grade D) coupled to four quick-disconnect fittings inside the booth.

f. Outlets for two abrasive blast hoses with remote controls.

g. A hose bib inside the booth connected to the facility's water supply to facilitate wash down.

h. Provisions for sampling the liquid effluent.

i. Grating-type floor (3/4-inch spacing) with sloping collection troughs below to ensure positive drainage to a filtration system.

j. Two 4-ft x 7-ft personnel doors through the sidewalls.

k. A 10-ft x 10-ft overhead door at the entrance to the booth.

l. Two 3-ft x 3-ft observation windows.

2.2.2.5 Facility modifications required to accommodate the booth were:

a. Extending existing air, water, and electrical lines to the booth.

b. Installing an 8-inch-diameter pipe inside the existing trench drain, connecting the booth effluent drain to the new pipe, and proving a clean out at the connection area.

c. Providing a 6-inch-high curb across the room and installing an insulated metal wall from curb to ceiling to act as a vapor barrier between the existing chemical stripping room and the new sodium bicarbonate blast booth.

d. Providing new overhead and personnel doors.

e. Modifying existing roof caps and providing mounting pads to hold intake and exhaust ducts and fans.

f. Removing and/or revising various electrical, water, and steam lines and other pipes, ducts, and equipment elements that would have interfered with installing the booth.

2.2.3 Test Equipment.

2.2.3.1 Before Air Force personnel accepted sodium bicarbonate blasting as a method of removing coatings, they had to produce quantitative data for determining the efficiency of the process. An efficient process in this instance is one that will economically strip typical military paint systems used for Air Force weapons while limiting blast-induced damage to the substrate. To see if sodium bicarbonate blasting met Air Force criteria SA-ALC contracted Battelle, Columbus, Ohio, to assess the process and provide test equipment and technical assistance.

2.2.3.2 The equipment included a test stand, test fixture, specimen positioning system, and sundry instruments, which were tested for integration with the spray booth and acceptable operation per SA-ALC specifications.

2.2.3.3 SA-ALC established the following technical and functional requirements for the test equipment:

a. A fixture that can hold strip-rate specimens larger than 12" x 24".

b. A fixture designed to hold a minimum of five Almen strip specimens.

c. A test stand that can adjust and hold fixed nozzle impingement angles of 30 and 90 degrees and standoff distances of 6 to 30 inches.

d. A two-axis (XY) programmable translation system that can position, in combination, the blast nozzle and optimization specimens, and effect a relative traverse of the optimization specimens through the blast stream at a controlled and repeatable rate of up to five inches/second.

e. Auxiliary materials/test equipment that will include a digital dry film thickness gage to measure the coating thickness on a nonferrous substrate to 0.00001 inch, and read a digital analytical balance to 0.1 milligram (mg), and a digital Almen arc height gage to 0.00001 inch.

2.2.3.4 Equipment Integration and Acceptance Tests.

2.2.3.4.1 Battelle furnished a test stand designed and fabricated to hold 12" x 24" test specimens. The fixture is made of extruded aluminum profile, which permits clamping of various sizes of test specimens by sliding clamps along slots in the profile.

2.2.3.4.2 The XY positioning system has remote programming controls for positioning specimens. It consists of a desktop computer, program board, cables and connectors for the motors and controls, and XY motor controllers. Battelle installed the program board and ran preliminary system checks at their Columbus facility before shipping to SA-ALC. After shipping the equipment to SA-ALC, Battelle re-assembled it, verified satisfactory operation and provided user manuals for the computer and the XY system to appropriate SA-ALC personnel.

2.2.3.4.3 The test stand can position relative nozzle-to-specimen standoff distances of 6 to 30 inches, and blast impingement angles (relative angle between the blast nozzle and the plane of the test specimen) of 30 to 90 degrees.

2.2.3.4.4 Protective features such as metal bellows to cover the traverse ways, lubricant to use on lead screws, and positive air pressure within the bellows assembly to exclude blast media were included as part of the procurement specification for the XY positioning system. These features give the system an integral means of resisting blast media intrusion that could damage it.

2.2.3.4.5 Battelle installed the government-furnished blast nozzle so it could not be disturbed by movements of the specimen positioning system. They also developed and explained methods for adjusting and locking standoff distance and impingement angle parameters to SA-ALC personnel.

a. Battelle showed SA-ALC personnel how to secure 12" x 24" specimens and an Almen strip fixture. Test specimens were installed successfully after 24" x 24" sheets supplied by Battelle were sheared to size.

b. The specimen positioning segment of the test stand (XY table) could translate 3" per second in the Y (vertical) direction and 5" per second in the X (horizontal) direction. Test stand positioning functions were evaluated by timing programmed displacements of the X and Y components over a known distance. The measured traverse rates obtained during the acceptance test were greater than 5" per second in the X direction and approximately 2.8" per second in the Y direction. This was deemed acceptable as displacements in the Y direction represent non-critical specimen translations between planned test sequences.

2.2.3.4.6 The digital analytical balance that Battelle supplied was set up to determine compliance with SA-ALC's technical requirements. The balance functioned properly at 0.0001 gram. Subsequent calibration by SA-ALC personnel proved the accuracy of the balance was satisfactory and within specifications.

a. An Almen strip fixture that could hold six Almen strip specimens simultaneously was available during equipment installation and acceptance testing. Tests conducted with this fixture during the initial phases of the process optimization showed that the fixture was satisfactory.

b. Battelle provided an Almen specimen arc height gage. The digital indicator, which is the principal component of the gage, could produce a readout of 0.00005 inch. The specification was for a minimum readout to 0.0001 inch.

c. Battelle obtained a digital dry film thickness gage for the project that could produce a minimum readout of 0.0001 inch on a nonferrous substrate. This gage also could produce this range of thickness readings on ferrous substrates. The manufacturer of the gage supplied calibration standards.

2.2.3.4.7 Acceptance testing were done according to the *Plan for Acceptance Test Procedures and Acceptance Test Specifications* for the test stand, test fixture, and programmable specimen positioning system. A copy of this plan is in Appendix III. Battelle also did preliminary operational testing according to the test plan. These tests showed that Battelle met the technical and functional requirements established by SA-ALC.

2.2.3.4.8 SA-ALC's technical and functional requirements were:

a. To make sure the specimen holding and positioning system is installed within the spray booth and is operational.

b. To provide fixturing to secure the government-furnished blast nozzle into the specimen holding and positioning fixture.

c. To provide a positioning system that can operate while experiencing the thrust forces, etc., exhibited during blasting applications.

d. To protect the specimen holding and positioning system so it can withstand the wet and abrasive blasting environment.

2.2.3.4.9 After the test stand, test fixture, and programmable sample positioning systems were installed in the spray booth, the blast nozzle was installed on the holding fixture to see if the fixture could secure the nozzle at a fixed position.

a. The blast system worked well with the test stand.

b. The test stand's integrity was scrutinized for a week in conjunction with blast operations associated with the initial process optimization efforts. The test stand was covered with plastic during blasting to augment the equipment protective features and to keep blast media from reaching its surface.

SECTION III - MARINE CORPS TEST PROCEDURES AND PRACTICE

3.1 TEST SPECIFICATIONS

3.1.1 Test Description.

a. Location - Initial testing was begun inside the Marine Corps blasting and cleaning facility, but was completed outside in the abrasive blast area because of the noise produced by the sodium bicarbonate blast system.

b. Personnel - The same blast operator was used during the entire test.

c. Waste collection - Waste was treated in the base's IWTP.

d. Damage criteria - For heavy iron and thick aluminum, observe the stripped vehicle or component for warping or alteration that would make the item unserviceable. Also, observe border material for damage.

3.1.2 Physical Characteristics.

a. Fatigue testing - One of the sodium bicarbonate blasting systems used for the test was operated above 14,000 pounds per square inch (psi) water pressure at the nozzle. This pressure was not high enough to damage the base material (thick steel or aluminum) of the equipment tested. Therefore, no fatigue testing was necessary.

b. Surface profile - Surface areas of stripped items were checked for the effectiveness of the sodium bicarbonate blast systems at removing paint and corrosion. While all of the blast systems removed the paint, none removed all of the corrosion.

c. Composite materials - All of the systems tested could damage composite materials such as fiberglass, if the operator dwells with the blast nozzle too long in one place.

3.1.3 Types of Material Stripped.

3.1.3.1 Protective Coating - Marine Corps ground combat and tactical equipment are rebuilt per Military Standard, MIL-STD-91621, which covers the IROAN procedures. Marine Corps equipment may go through the IROAN process one or more times before being completely rebuilt. Therefore, the equipment may have several layers of primer and top coats before being completely stripped. Ground combat and tactical equipment are painted per U.S. Marine Corps technical manual, TM 4750-15/1 using chemical agent resistant coating (CARC).

a. Primer - MIL-P-53022, Type I: Primer, Epoxy Coating, Corrosion Inhibiting, Lead and Chromate Free. The table at Paragraph 1.4.2.2.1 of this report provides the thickness and number of coats on specific test samples.

b. Finish coating - MIL-C-46168, Type II: Coating, Aliphatic Polyurethane, Chemical Agent Resistant. The table at Paragraph 1.4.2.2.1 of this report provides the thickness and number of coats on specific test samples. Test panels were painted according to TM 4750-15/1 with two coats of finish coating at 3.2 mils.

3.1.3.2 Border Material - Depending on the vehicle stripped, border material can be rubber gaskets, fiberglass, or glass.

3.2 PRACTICE AND PROCEDURES

3.2.1 The three systems tested all use sodium bicarbonate mixed with water. The Aqua Miser and Jet Stripper use high-pressure water to remove paint with sodium bicarbonate injected to aid removal effectiveness. The Accustrip can be used dry or water can be added at the nozzle when dust control is required. High-pressure air propels sodium bicarbonate against the surface and sharp edges of the media cut the paint away from the base metal. Recommended standoff distances and blast angle for the specific systems tested are:

Manufacturer	Standoff Distance inches	Blast Angle degrees
Accustrip	18	30
Aqua Miser	4 to 6	40
Jet Stripper	6 to 8	30 to 45

3.2.2 Rinse Procedures. Visually inspect items for complete sodium bicarbonate removal after stripping per established rinse procedures. The procedure for removing residues resulting from wet or dry abrasive material depends on the item's size and construction, and the type of material it is made from. Submerge small parts, submerge for five minutes in a dip tank with the rinse water heated to 120 degrees F. For larger parts and equipment, rinsing should start at the highest point of the piece and proceed to the lowest. Thoroughly wash jointed areas to make sure all sodium bicarbonate residue is removed. Before applying a new coating, inspect the item again for surface contaminants.

a. A low-pressure water rinse with a flow rate of 5 gallons per minute (gpm) at 45 psig and a wash rate of approximately 50 sq ft/min of surface is satisfactory. Three rinse cycles, separated by a two-minute interval are recommended for water at a minimum temperature of 70 degree F. Two rinse cycles, separated by a two minute interval is recommended for a hot water rinse with a water temperature of 120 degrees F.

b. A high-pressure water rinse with a flow rate of 3 gpm at 1000 psig and a wash rate of approximately 50 sq ft/min of surface is satisfactory. Two rinse cycles, separated by a two-minute interval is recommended for water at a minimum temperature of 70 degrees F. One rinse cycle is recommended for a hot-water rinse with a water temperature of 120 degrees F.

3.2.3 Repainting test methods, including corrosion and adhesion (tape) testing, will be accomplished in accordance with (IAW), TM 4750-15/1.

3.2.4 Operators must be trained to use specific sodium bicarbonate blast systems. They must follow the manufacturer's instructions for proper operation of the equipment and the manufacturer's recommended method for maintaining safe working pressure. The recommended practice for the operator in stripping an item for the first time is to always start slowly at the lowest pressure to prevent damage. If practical, the operator should use a test specimen to set up satisfactory operating parameters.

3.2.5 Operator Safety Requirements:

a. While blasting operators shall never point the blast nozzle at themselves or other people.

b. Operators must always wear double hearing protection while the sodium bicarbonate blasting equipment is operating.

c. Operators must wear an air hood blast helmet with an air-supplied respirator and an optional half mask for nuisance dust when using the sodium bicarbonate blast system in a wet or dry mode.

d. Operators must wear rain suits, rubber gloves, and safety toed rubber boots.

e. Personnel working with the operator and personnel working within 120 feet of the blast equipment shall wear double hearing protection.

3.3 ENVIRONMENTAL

3.3.1 Wastes Generated.

3.3.1.1 Used wet - The three systems tested produced a wet slurry when the equipment was stripped of paint. The slurry consisted of the sodium bicarbonate media, water, paint chips, and miscellaneous residues such as dirt and grease.

3.3.1.2 Used dry - Of the three systems, only the Accustrip system was tested using dry media. Accustrip produced a nuisance dust, paint chips, and miscellaneous residues such as dirt and grease.

3.3.2 Waste Treatment Processes - Wastes generated were treated at the IWTP.

3.3.3 Material Safety Data Sheets (MSDS) - see Appendix IV.

3.3.4 EPA Standards and Categories - None currently apply to Marine Corps Logistics Base, Albany.

3.3.5 Environmental Limitations.

3.3.5.1 Currently, sodium bicarbonate creates no environmental or waste disposal problems. Paint chips and miscellaneous residue, such as dirt and grease, resulting from the process may be considered as hazardous waste.

3.3.5.2 Operators are required to wear an air hood blast helmet with an air-supplied respirator and an optional half mask respirator when using the sodium bicarbonate blast system in a wet or dry mode.

3.3.5.3 Because of the noise and dust produced (wet or dry mode), the sodium bicarbonate blast system should only be operated in an isolated area outdoors (at least 120 feet away from the nearest unprotected employee) or indoors, only in an abrasive blast room.

SECTION IV - AIR FORCE TEST PROCEDURES AND PRACTICE

4.1 PROCESS OPTIMIZATION

4.1.1 Introduction.

The process optimization study was conducted to find operating parameters that would produce the most efficient paint stripping rate with minimal blast imparted damage to substrate material. Production rates obtained during the optimization testing were determined by calculating the rate at which paint was removed from large test panels. Potential blast damage was evaluated by measuring deformation of small test coupons following paint removal.

4.1.2 Technical Discussion.

4.1.2.1 Experimental Procedures.

4.1.2.1.1 Materials for this study consisted of a 2024-T3 bare aluminum alloy with a nominal thickness of 0.032 inch. Battelle prepared test panels for sodium bicarbonate stripping to the following standards:

a. Test panels were cleaned with Alkaline detergent using MIL-C-25769 material.

b. The Panels were Deoxidized using MIL-C-38334 material.

c. Within four hours a chemical conversion treatment was performed using material conforming to MIL-C-81706 and applied IAW MIL-C-5541.

d. An epoxy primer conforming to MIL-P-23377 was applied to a dry film thickness of 0.0006 to 0.0009 inch.

e. A polyurethane topcoat conforming to MIL-C-83286 was applied to a dry film thickness of 0.0017 to 0.0023 inch.

4.1.2.1.2 After painting, the test panels received a 7-day air cure in a controlled laboratory environment, maintained at 72 degrees F and 50 percent relative humidity. An artificial (accelerated) aging was then accomplished by curing the test panels in an oven at 210 degrees F for 96 hours.

4.1.2.1.3 A Government furnished Accustrip Blasting System using ARMEX blast media as previously described was used for the optimization testing. Control of the paint stripping process was achieved by using a multi-axis, motor-driven table assembly to traverse the blasting nozzle across the surface of the test panel. The multi-axis table assembly was computer controlled. The horizontal axis could achieve speeds up to five inches per second; and, it was programmed to move through a predefined velocity profile while traveling the length of the table. The test panel was mounted to a stationary backstop that was connected to the table assembly to maintain a constant standoff distance between the nozzle outlet and the test panel surface. The blast nozzle was mounted to the vertical axis of the table assembly. This axis was designed to rotate with respect to the horizontal axis so the impingement angle of the blast stream could be adjusted.

4.1.2.2 Production Rate Assessment.

4.1.2.2.1 The following initial test parameters investigated during process optimization were recommended by the manufacturer:

a. Various speeds for the blast nozzle to traverse the horizontal axis of the table assembly.

b. A blast stream impingement angle of 60 degrees.

c. Blast stream pressure of 60 psi.

d. Injected water pressure of 300 psi.

e. A blast media flow rate of three lbs per min (2.5 psi differential pressure).

f. A standoff distance between the nozzle outlet and the test panel of 18 inches.

4.1.2.2.2 Based on the manufacturer's experience with sodium bicarbonate blasting, the media flow rate, blast stream pressure, and impingement angle were expected to have the most influence on the rate of paint removal from the test panels. Therefore, initial paint stripping tests involved varying those process parameters while using a range of traverse speeds to evaluate the effectiveness of and potential production rates for the process.

4.1.2.2.3 Following these tests, the effects of the injected water pressure and the standoff distance were studied more closely. During the preliminary evaluation of a process parameter, the horizontal axis of the table assembly was programmed to traverse the 24-inch length of the test panel at various speeds. The width and completeness of the stripped path indicated the effectiveness of the process. Based on the area of stripped paint and the rate at which it was removed, an equivalent production rate was calculated.

4.1.2.3 Qualitative Damage Assessment.

4.1.2.3.1 As part of the procedure to optimize sodium bicarbonate blasting, an assessment of blast-induced damage was required to be certain that Air Force damage criteria would not be exceeded. Potential damage to the thin aluminum substrates was monitored by calculating changes in the arc height of test coupons, called Almen specimens, produced by blasting with this process.

4.1.2.3.2 The Almen specimens used for the arc height calculations were sheared from 0.032-inch-thick painted aluminum sheets to dimensions of 0.75 x 3.00 inches. The 3.00-inch dimension was oriented in the sheet rolling direction. All Almen specimens were sheared from painted panels and were blasted on a common face of the original panel.

4.1.2.3.3 The procedure used to develop the arc height data included quasi-saturation blasting of the coupons, which was equivalent to four depainting cycles. The coupons were not repainted between the initial depainting cycle and subsequent blast cycles. This form of testing represented a worst-case situation that might occur from excessive dwell time during paint removal or the equivalent of the expected depainting cycle of Air Force aircraft.

4.1.2.3.4 The arc height coupons were mounted in a test fixture that constrained the coupon at two points along each of the 3-inch sides. The constraint locations were approximately 2 inches apart. The test fixture held up to six coupons, which permitted conditioning of multiple coupons at identical parameters. The fixture was mounted to the backstop used for the test panel paint stripping.

4.1.2.3.5 The fixture was mounted so that the blast stream traversed the coupon parallel to the rolling direction of the aluminum alloy sheet. Therefore, one pass of the blast stream fully covered the test coupon. Arc height coupons were depainted using the identical process parameters as the associated test panel. Due to the process parameters being studied the coupons were measured before and after the depainting process to calculate the arc height.

4.1.3 Results.

4.1.3.1 The results of the paint stripping production rate assessment will be discussed with the results of the arc height damage assessment, since the data was developed for a particular set of process parameters. The process parameters investigated in the optimization study showed extensive interdependence. As a result, it was not feasible to study the range of just one parameter while leaving all others constant. A summary of the results of the process optimization follows:

Summary of process optimization test results.

Standoff Distance, inches	Impingement Angle, degrees	Water Pressure, psi	Blast Stream Pressure, psi	Differential Pressure, psi	Production Rate, ft^2/min	Change in Arc Height, mils
18	60	300	60	2.5	0.26	16.75
18	60	300	60	2.5	0.31	15.98
18	60	300	60	2.5	0.31	12.03
18	30	300	60	2.5	0.17	7.78
16	30	300	60	2.5	0.16	
22	30	300	60	2.5	0.15	

Summary of process optimization test results.

Standoff Distance, inches	Impingement Angle, degrees	Water Pressure, psi	Blast Stream Pressure, psi	Differential Pressure, psi	Production Rate, ft^2/min	Change in Arc Height, mils
12	60	300	60	2.5	0.55	14.88
18	60	300	60	2.5	0.31	16.42
12	60	300	45	2.5	0.17	12.48
12	60	300	45	2.5	0.16	11.50
18	45	300	45	2.5	0.16	8.75
18	45	0	40	2.5	0.23	
18	45	0	50	2.5	0.42	
18	45	0	60	2.5	0.52	
18	45	0	60	2.5	0.47	
18	45	250	60	2.5	0.36	
18	45	110	60	2.5	0.52	
18	45	110	60	2.5	0.47	10.88
18	45	110	50	2.5	0.25	10.80
18	45	150	50	2.5	0.16	
18	45	150	60	1.5	0.16	
18	45	150	60	2.5	0.25	
18	45	150	60	2.5	0.18	
18	45	150	60	5.0		11.03
18	30	150	60	5.0	0.21	6.50
18	30	150	50	5.0	0.13	6.05
18	30	150	50	3.75	0.14	6.70
18	30	150	70	5.0	0.26	7.60
18	30	150	70	3.75	0.24	6.37
18	30	150	70	3.75	0.23	7.20
18	30	150	80	3.75	0.16	7.93
21	30	150	80	3.75	0.34	8.22
21	30	150	70	3.75	0.18	7.22
21	30	150	70	3.75	0.11	6.43
24	30	150	70	3.75	0.21	6.90

4.1.3.2 During the optimization process various conditions were adjusted, and the paint removal rate and corresponding change in arc height was calculated. A production rate of approximately 0.3 ft^2/min was achieved using the manufacturer's recommended parameters; however, the change in arc height of the test coupons was greater than 12 mils, which significantly exceeds the Air Force damage criteria of 5 mils maximum. Following the initial paint stripping, the impingement angle and the blast stream pressure were adjusted to reduce the potential damage to the aluminum substrate. Decreasing the impingement angle to 30 degrees, reduced the change in arc height by about 50 percent; however, the production stripping rate was also reduced by 50 percent.

4.1.3.3 Small adjustments in the standoff distance produced no appreciable changes in the production rate. Next, the blast stream pressure was reduced to 45 psi. This resulted in lower arc heights but no change in the production rate. A set of test panels was depainted with no injected water at various blast stream pressures to study the effects of the water on the production rate. With no water injected into the sodium bicarbonate blast stream, production rates increased with blast stream pressure to a maximum of approximately 0.5 ft^2/min. However, the injected water was required to reduce the concentration of airborne sodium bicarbonate.

4.1.3.4 The water pressure was set to 150 psi and additional test panels were depainted at an impingement angle of 45 degrees and a blast stream pressure of 60 psi. Production rates reached 0.25 ft^2/min, but the change in the coupon's arc height was still above 10 mils. The impingement angle was reduced further to 30 degrees. To compensate for the reduced production rates at this angle, the media flow rate was increased by increasing the differential pressure of 2.5 psi to 3.75 psi. The resulting paint stripping rates were approximately 0.2 ft^2/min and the coupon arc height was reduced to below 8.0 mils.

4.1.3.5 A set of test panels was stripped using these process parameters with various standoff distances. The resulting arc height calculations and production rates were unchanged. The optimum process parameters determined in this study were:

Impingement angle	= 30 degrees
Blast pressure	= 60 psi
Water pressure	= 150 psi
Media flow rate	= 3.75 psi
Standoff distance	= 18 inches
Traverse rate	= 0.8 inches/second.

4.2 PROCESS CHARACTERIZATION

4.2.1 Introduction.

4.2.1.1 Because blast type depainting processes often damage the coating system while removing paint, the potential exists also for such a process to impart blast related damage to the substrate. The initial optimization steps of this program tracked qualitative damage as a guiding index. The next step entails thoroughly assessing possible substrate damage. This step is significant in that processes being considered for Air Force validation must not produce unacceptable substrate damage.

4.2.1.2 Damage appraisals conducted in this program were:

a. Eroded cladding material resulting from multiple applications of the blast process.

b. Increased surface roughness resulting from the blast process.

c. Blast-imparted residual stresses determined by X-ray diffraction.

d. Residual stress saturation per blast cycle, per developed process.

e. Possible changes in the tested substrate's fatigue life characteristics.

f. Possible increase in the rate of fatigue crack growth attributable to the blast process.

4.2.1.3 Test materials for this study were 2024-T3, 0.032-inch bare and clad aluminum alloy, and 7075-T6, 0.032-inch bare and clad aluminum alloy. Notched fatigue and fatigue crack growth rate (FCGR) testing was conducted with the 2024-T3 bare substrate materials. All substrate materials were examined for increased surface roughness. Quantitative analysis of residual stresses by X-ray diffraction and qualitative residual stress saturation determinations were done with the bare alloys.

4.2.1.4 Test materials were painted per T.O. 1-1-8. They were artificially aged by heating to 210 degrees F for 96 hours, after a 7-day air cure cycle. The panels were coated with epoxy primer MIL-P-23377 and polyurethane topcoat MIL-C-83286, color No. 36081. A set of panels was prepared with MIL-TT-P2760 Koroflex primer and MIL-C-85285 high solids polyurethane, color No. 36173. This set was comprised of 2 panels of each alloy used in the program.

4.2.1.5 Blast parameters used for all specimen conditioning in the materials characterization portion of the program were as follows:

Blast Medium	= ARMEX Maintenance Grade XL Sodium Bicarbonate
Standoff Distance (SOD)	= 18 inches
Impingement Angle	= 30 degrees
Blast Pressure	= 60 psi
Water Pressure	= 150 psi
Traverse rate	= 0.8 inch/second

4.2.1.6 The process parameters listed above are derived from the process optimization. Because several months passed between the time the different tasks were worked, a series of tests were used to check these parameters for production rate versus Almen arc height data before starting. These tests showed an average production rate after five trials of 0.29 ft^2/min, which was better than previous test results, but close enough to say that the production had not changed significantly. As an additional check, six sets of five Almen specimens of 0.032-inch-thick 2024-T3 bare alloy were blasted to provide a statistically sound baseline data set for delta arc height (Δh). The mean Δh for this data set was 5.11 +/- 0.61 mils. These specimens were blasted with the blast stream parallel to the roll direction, which can produce approximately 20 percent higher Δh measurements for this alloy than blasting with the stream held perpendicular to the roll direction. In past work of this nature Battelle has used the protocol of blasting perpendicular to the roll direction.

4.2.2 Technical Discussion.

4.2.2.1 Cladding erosion evaluations were made by determining cladding loss by weight per blast cycle. Specimens used for this portion of the materials characterization were unpainted Almen specimens. Erosion test specimens were prepared by thoroughly cleaning the surface to be blasted before the initial weighing to reduce the chance of including surface contaminants or oxides as part of the initial weight. This was accomplished by first lightly abrading the surface with a SCOTCH-BRITE pad, which was followed by a solvent wipe with methylethylketone. It was assumed that this abrasion process did not remove any significant portion of the cladding.

4.2.2.2 Surface roughness measurements were made on unpainted Almen specimens of each alloy used in this program. Specimen sets of six were grouped by alloy type. Each of the specimens was blasted to some incremental cyclic value of one to six blast cycles to track any surface roughness changes that might occur as a cumulative effect.

a. Almen specimens used for this study were cleaned and degreased before characterization by surface profile. Profile measurements were made at five locations on each specimen over a length of 0.03 inch, then repeated for a total of five measurements at each location. The statistical average of the 25 trials per specimen makes up the data presented in this report.

b. The two surface parameters delineated in this report are average roughness (R_a) and mean of the maximum peak-to-valley height (R_{tm}) of the surface profile. R_a is the arithmetic mean of the departure of the measured surface profile from a calculated mean line. The R_{tm} parameter is defined as the arithmetic of all R_{ti} values obtained in an assessment (measurements made over the 0.03-inch specimen length). R_{ti} is the maximum peak-to-valley height of the profile found in one sampling length.

4.2.2.3 Blast-imparted residual stresses were determined by x-ray diffraction for five Almen specimens each of 2024-T3 bare alloy and 7075-T6 bare alloy. This work was completed on a subcontract to Lamda Research and the results are reported in Appendix V. Almen specimens were sheared from painted panels to dimension. They were conditioned by undergoing one blast cycle of paint stripping, plus three cycles at the same parameters and production rate. All Almen specimens were blasted with the roll direction parallel to the orientation of the blast stream. The two sets each included two Almen specimens that were unrestrained at the time of baseline strain measurements. At the time the specimens were blasted, all were constrained by epoxy to 0.25-inch steel backing plate. All strain measurements made after conditioning were conducted with the Almen specimens in this constrained state.

4.2.2.4 Blast saturation data was developed to give the qualitative degree of residual stress saturation, and the point, in terms of blast dwell time, this cumulative effect should be saturated. Parameters measured are elapsed time (ET) of blasting and Δh of unpainted Almen specimens of 0.032-inch-thick 2024-T3 bare alloy and 7075-T6 bare alloy. Almen specimen Δh is not a direct measure of blast-induced cold work strains, but a change in the bending moment of the unrestrained specimen produced by the residual stresses associated with the cold work process. As such, Δh measurements offer a relative gage of the degree of blast-imparted residual stresses. Saturation data presented in this report for a given ET is the arithmetic mean of three specimens of common material, ET, and process parameters. Incremental blast times used for this study included up to 45 seconds of blasting.

4.2.2.5 Fatigue Life - Notched Specimens/Testing.

4.2.2.5.1 Fatigue specimens of 2024-T3 bare aluminum alloy initially were sheared from "as received" panels and from painted panels after sodium bicarbonate blasting. All fatigue specimens were machined to final dimensions. Fatigue specimens are oriented with the sheet rolling direction corresponding to the 12-inch dimension of the specimen and normal to the blast direction. Surface flaws (notches) were produced by a tool designed to produce the desired notch geometry (figure 1) in the specimen surface. All baseline specimens were alkaline washed and aged at 210 degrees F for 98 hours.

Figure 1. Notched fatigue specimen

4.2.2.5.2 Notched fatigue specimens (with the exception of the notching procedure) were tested following the guidelines of ASTM E466. All fatigue specimens were cycled under load control with a sinusoidal waveform at 10 hertz. Test loads were constant amplitude with a + 0.1 stress ratio. The nominal maximum stress for the 0.032-inch material is 33 thousand pounds per square inch (ksi).

4.2.2.5.3 Experimental fatigue specimens were conditioned by blasting painted panels previously notched on the front or back blast surface. Ten fatigue specimens were sheared from each blasted panel. The panels from which specimens were fabricated underwent a total of four blast cycles, or one strip cycle plus three simulated strip cycles.

4.2.2.6 Fatigue Crack Growth Specimens/Testing.

4.2.2.6.1 FCGR specimens were 2024-T3 bare substrate materials sheared from as-received panels and from painted panels after sodium bicarbonate blasting. All FCGR specimens were machine finished to final dimensions. A 1/8-inch-diameter hole was drilled through the center of the specimen (test section). An initial 0.040-inch starter notch was then machined by electrical discharge machining (EDM) using a 6-mil traveling wire cut. All FCGR specimens had the sheet rolling direction oriented with the 12-inch dimension of the specimen and normal to the blast direction.

4.2.2.6.2 FCGR specimens were tested following the guidelines of ASTM E647. All were cycled under load control with a sinusoidal waveform at 10 hertz. Test loads were constant amplitude with a +0.1 stress ratio, and a maximum load of 1120 pounds. The nominal maximum stress for the 0.032-inch material is 8,750 psi. Crack growth measurements were made with cast epoxy KRAK gages.

4.2.2.6.3 Experimental FCGR specimens were prepared by blasting painted panels, then shearing five specimens from each of the blasted panels. The panels from which the specimens were fabricated underwent a total of four blast cycles, one strip cycle plus three simulated strip cycles.

4.2.3 Test Results.

4.2.3.1 Cladding Erosion.

4.2.3.1.1 Cladding erosion data for the two alloys is presented in Figures 2 and 3. The erosion percentage data is calculated on the basis of a nominal cladding thickness of five percent (per manufacturer's data, per side) of the total sheet thickness. Since the specific densities of cladding are nearly identical to those of tempered alloys, the weight loss was correlated to volumetric loss by assuming the nominal thickness was five percent of the 0.032 inch sheet thickness.

4.2.3.1.2 Figures 4 and 5 are photographs of a cross-sectional view of one specimen each of the two clad alloy materials. These photographs depict the blasted sides of the specimens after six blast cycles and a view of the unblasted sides for comparison. It appears from these photographs that all of the cladding has been eroded for both specimens, thereby implying that the cladding thickness was something less than five percent. This also was evidenced by measuring the cladding thickness of the photographed specimens. Because there was no further investigation to determine the status of all the specimens in this fashion, the nominal five percent thickness for calculating erosion was used.

Figure 2.
Cladding erosion for
2024-T3 clad aluminum

Figure 3.
Cladding erosion for
7075-T6 clad aluminum

Figure 4. Cross-sectional view of 0.032-inch, 2024-T3 clad specimen.

Figure 5. Cross-sectional view of 0.032-inch, 7075-T6 clad specimen.

4.2.3.1.3 Figures 2 and 3 are representations of mean weight loss from three trials converted to mean percent cladding loss, based on the presumption that the nominal cladding thickness per side was five percent. The following tables are the tabulated percent cladding loss (Δ%) for the 2024-T3 and 7075-T6 materials, respectively.

Percent cladding loss for 2024-T3 Almen specimens

$\Delta\%_1$	$\Delta\%_2$	$\Delta\%_3$	Mean Δ%	Blast Time, seconds	Blast Cycles
1.57	1.56	1.48	1.54	3.75	1
2.75	2.77	2.83	2.78	7.50	2
3.45	3.54	3.61	3.54	11.25	3
3.81	3.76	3.97	3.85	15.00	4
4.08	4.07	4.09	4.08	18.75	5
3.97	4.07	4.06	4.03	22.50	6

Percent cladding loss for 7075-T6 Almen specimens

$\Delta\%_1$	$\Delta\%_2$	$\Delta\%_3$	Mean Δ%	Blast Time, seconds	Blast cycles
1.30	1.57	1.46	1.44	3.75	1
2.60	2.56	2.66	2.61	7.50	2
3.16	3.13	3.31	3.20	11.25	3
3.64	3.62	3.43	3.56	15.00	4
3.65	3.53	3.66	3.61	18.75	5
3.55	3.58	3.31	3.48	22.50	6

The percent loss in the tables above is the absolute loss or total loss, when the presumed maximum loss possible is the nominal five percent total thickness per side of the laminate sheet.

4.2.3.2 Surface Roughness.

4.2.3.2.1 Figure 6 represents surface profiles of the various Almen specimens after the initial blast cycle. The codes are as follows:

SF7B = 7075-T6 bare aluminum specimen
SF2B = 2024-T3 bare aluminum specimen
SF7C = 7075-T6 clad aluminum specimen
SF2C = 2024-T3 clad aluminum specimen

Figure 6. Surface profiles of aluminum specimens after the initial blast cycle.

4.2.3.2.2 Bare surfaces are much smoother than clad surfaces following one blast cycle. Further blast cycles increase the roughness of bare surfaces, while the clad surfaces become smoother. Figures 7 and 8 illustrate these trends.

Roughness (R_a), μ inch

Figure 7. Surface roughness for aluminum specimens subjected to multiple cleaning cycles.

Peak To Valley (R_{tm}), μ inch

Figure 8. Peak to valley measurements for aluminum specimens subjected to multiple cleaning cycles.

4.2.3.3 Residual Stresses Measured by X-ray Diffraction.

The stress calculations and the methods to make those calculations used by Lambda Research, Inc., are in Appendix V.

4.2.3.4 Qualitative Residual Stress Saturation.

The saturation response of the substrate to the sodium bicarbonate blasting system used in this study was Almen Δh as a function of elapsed blast time (ET) for unpainted 2024-T3 bare and 7075-T6 bare Almen specimens. This data is presented in Figures 9 and 10 for the 2024-T3 and 7075-T6 specimen sets, respectively. The overall response for the 2024-T3 bare Almen specimens is higher than the response of the 7075-T6 Almen specimens by a factor of two or greater. However, the point at which saturation occurs is about the same for both materials.

Figure 9. Almen saturation curve for 2024-T3 bare aluminum.

Figure 10. Almen saturation curve for 7075-T6 bare aluminum.

4.2.3.5 Fatigue Life - Notched Specimens.

4.2.3.5.1 Figure 11 compares the distribution of the $\log_{10}$ (fatigue life) values of the as-received (baseline after alkaline wash and heating to 210 degrees F for 96 hours) and the blasted specimens with front and back surface notches. The data sets are comprised of ten as-received specimens and ten specimens for each notch condition. The following table presents the mean fatigue life, standard deviation, and alterations of the experimental fatigue life as a percent change in fatigue life after sodium bicarbonate blasting for four cycles for each data set (notch condition).

Fatigue life statistical data

Figure 11. Fatigue life comparison of front and back surface notched specimens to baseline (as-received) specimens.

4.2.3.5.2 The effect of sodium bicarbonate blasting on the substrate fatigue life was determined by comparing the mean fatigue life of the experimental specimens for each notch condition with the mean fatigue life of the as-received specimens. An analysis of the mean fatigue life of the baseline and experimental specimens was made to assess the statistical significance of any changes of fatigue life attributable to the process. The test achieved a confidence level of 95 percent.

4.2.3.6 Fatigue Crack Growth Rate.

4.2.3.6.1 Figures 12 - 16 represent the baseline and experimental FCGR data. These figures are log-log plots of crack growth per load cycle (da/dN) as a function of a change of the stress intensity factor (ΔK).

a. Figure 12 shows all of the baseline FCGR data and Figure 13 shows curve fit plots of each baseline FCGR specimen. Figures 14 and 15 are similar treatments of the experimental FCGR data. Figure 16 is a curve fit comparison of the baseline and experimental FCGR data, with each condition treated as a complete data set.

b. The fitted regression curves are third-degree polynomials of the form:

$$\log_{10} (da/dN) = a + b \log_{10} (\Delta K) + c \log_{10} (\Delta K3) + d \log_{10} (\Delta K3)$$

where: a, b, c, and d are parameters estimated by the regression fit.

c. All curve fittings used in this analysis were regression fits of this form. In comparing baseline with experimental FCGR data, all specimens for each condition are treated as one data set each, since there is perceptively little scatter in the data of either data set.

4.2.3.6.2 Several notable observations that can be made from these figures follow:

a. The data scatter observed for the baseline data appears to be greater than the scatter seen with the blasted data.

b. The blasted data indicate similar crack growth rates for both experimental data sets.

c. The crack growth rate displayed by the blasted data set increases slightly at lower values of ΔK.

d. The difference of crack growth rate manifested by the blasted data sets could be construed to lie within the scatter of the baseline data.

4.2.3.6.3 The question now arises about whether the small differences in crack growth rate are real, or artificial due to statistical variance within the data. To find the answer, consider the following assumptions and analyses:

a. If a linear regression fit to the as-received da/dN and ΔK represent the true model, the correlation coefficient for this regression fit was 0.96. As this value approaches 1.0, the fit of the data improves.

b. Postulate the hypothesis that the effect on the substrate resistance to cracking is negligible.

c. Probe the hypothesis by inspecting the residuals of the da/dN data. The residual is the difference between the observed (experimental) da/dN behavior and that predicted by the baseline regression fit.

4.2.3.6.4 The hypothesis may now be tested by examining the mean residual of the blasted material to consider whether it is equal to the mean residual of the baseline material. Because the mean residual of the baseline material must be zero by definition, the hypothesis is rejected if:

where:

X_m : mean residual of blasted material

Φ : standard normal distribution function

α : significance level

σ_1 : standard deviation of baseline material residual distribution

σ_2 : standard deviation of blasted material residual distribution

n_1 : number of data points in as-received material residual distribution

n_2 : number of data points in blasted material residual distribution

4.2.3.6.5 The results of these calculations show that, at a confidence level of 95 percent, the hypothesis is rejected. Therefore, the decrease of crack growth resistance observed probably is not an effect of small statistical variables within the data.

4.2.3.6.6 The regression fit models also are used to qualify the change of crack resistance. This data is in Figure 17 as a plot of percent change ($\Delta\%$) of crack growth for the range of ΔK values examined in this study. The percent change is derived by the difference of the da/dN values predicted by the regression fit of the FCGR data for the baseline and blasted data sets. It is apparent from Figure 17 that the change of crack resistance is not severe, except at the lower ΔK range, and the increased crack growth rate tend to dissipate at higher values of ΔK.

Figure 12. Baseline fatigue crack growth rate data.

Figure 13. Curve fit baseline fatigue crack growth rate data.

Figure 14. Experimental fatigue crack growth rate data.

Figure 15. Curve fit experimental fatigue crack growth rate data.

Figure 16. Experimental versus baseline fatigue crack growth rate data.

Figure 17. Percent change of experimental FCGR versus baseline FCGR.

4.2.3.7 Fatigue Specimen Fracture Surface Analysis.

It was unnecessary to conduct anything other than macroscopic observations of the fracture surfaces as all specimens exhibited crack initiation within the machined flaw (front or back surface notch).

4.2.3.8 Conclusions/Discussions.

4.2.3.8.1 Cladding Erosion.

Under the conditions by which these tests were conducted, it can be concluded that the sodium bicarbonate blasting process will erode most, if not all, of the clad laminate after four to six blast cycles. This condition might be alleviated by further developing or optimizing the process and/or operational parameters. It is also very likely that the process parameters used for this study are not the best for use with cladding materials, as the low impingement angle tends to accelerate erosion of these soft materials.

4.2.3.8.2 Surface Roughness.

Initial increased surface roughness on either of the bare or clad alloys was not excessive, especially on the bare materials. Subsequent decreased roughness on clad specimens unfortunately coincides with the erosion of the cladding from these specimens.

4.2.3.8.3 Qualitative Residual Stresses.

Data developed within this program and presented in this report have shown that the sodium bicarbonate blasting process tested in this program does not reach saturation within a reasonable number of blast cycles. The total number of blast cycles corresponds to the cyclic depainting expectancies of most Air Force aircraft. This data agrees with the Almen data based on four blast cycles, which shows approaching saturation within the initial cycle or cycles. The level is at the high end of the values commonly accepted by the Air Force. It is the Air Force's desire to produce no more than one to two mils, but four to five mils has been commonly accepted as the maximum allowable limit.

4.2.3.8.4 Residual Stresses by X-ray Diffraction.

See Appendix V.

4.2.3.8.5 Fatigue Life - Notched Specimens.

4.2.3.8.5.1 A comparison of the mean fatigue life values of the front and back notch conditions and the baseline data set showed no statistical significance of perceived variations between the data sets. Fatigue life improvements observed with the front notch condition following sodium bicarbonate blasting were statistically significant and unattributable to inherent scatter within the data sets. This gives reason to believe that this effect is therefore real. On the other hand, the analysis comparing the fatigue life means of the front notch and baseline conditions indicate no justification to believe there is any statistically significant difference between the two data sets.

4.2.3.8.5.2 In summary the fatigue life study, as conducted under this program, shows that this process has not degraded the fatigue life of the substrate material used for this study. This condition may not hold true for other materials.

4.2.3.8.6 Fatigue Crack Growth Rate Tests.

FCGR results do show a small degradation of the FCGR characteristics of the substrate material as a result of the sodium bicarbonate blasting as done in this study. This effect is real, but it occurs only at lower ranges of ΔK. At ΔK values greater than 8, the increase of FCGR is less than 10 percent, with the maximum FCGR increase at $\Delta K = 7$ of 26 percent. The dominant trend of the data implies that conditioning sodium bicarbonate blasting systems produces little or no change of FCGR characteristics of the substrate material used in this study.

APPENDIX I

APPENDIX II

Supplementary Sodium Bicarbonate Blasting Process Information

The supplementary information presented in this appended section pertains to additional sodium bicarbonate based systems that have been identified as having a potential for paint stripping that may be useful to the Air Force. This discussion relates some basic information about two sodium bicarbonate based systems that characterize these processes as significantly different from the system reported in this document. The observations offered in Appendix II should not be considered conclusive since either the evaluations are not complete, or, are informal, precursory tests.

The two systems to be discussed herein are manufactured by WhiteMetal, Incorporated (JET STRIPPER), and Carolina Equipment and Supply Company (Aqua Miser). The informal tests conducted with the WhiteMetal Jet Stripper process were done by SA-ALC and WhiteMetal staff only, with no participation by Battelle in these tests. The tests conducted at SA-ALC with the Carolina Equipment, Aqua Miser were done as a cooperative effort between SA-ALC and WR-ALC in support of a program contracted through Battelle from WR-ALC to provide a more formal assessment of the Aqua Miser system.

The features that differentiate both systems from the sodium bicarbonate blasting system evaluated and reported here are the use of water to provide acceleration of the abrasive medium and a significant reduction of the flow rate (- 0.5 pound/minute) of the blast medium. The JET STRIPPER is somewhat closer in nature to the Accustrip process in that it relies on pneumatic propulsion of the abrasive media, but augments the particle acceleration through hydraulic reaction (3000 psi water pressure). The Aqua Miser process differs from both systems in that the particle acceleration is accomplished by hydraulic reaction (15,000 psi water pressure) alone.

The testing of the Aqua Miser system was done at SA-ALC in order to make use of the controlled test environment at that facility. However, the attempts to develop optimized process parameters for the Aqua Miser system were not productive on this occasion due to equipment malfunctions (nozzle tips in particular) and extreme fluctuations in the service air which rendered efforts to control media flow practically useless. Previous tests with this system had demonstrated a potential for high strip rates coupled with apparent substrate damage (low Almen Δh measurements). The Aqua Miser system will undergo further testing whenever the above problems can be rectified and the test results will be reported to WR-ALC by Battelle at that time.

The tests conducted by SA-ALC with the JET STRIPPER system looked at strip rates and potential for substrate damage. SA-ALC reported that these criteria were satisfied in this informal round of testing. No decision has been indicated by SA-ALC, or the Air Force, regarding formal testing of the JET STRIPPER process.

Both systems discussed in Appendix II have demonstrated a potential for satisfying Air Force paint stripping criteria through preliminary evaluations. Further testing of either system might do well to examine the mass flow issue since both systems feature a lower mass flow than the Accustrip system and both alternative systems appear to offer a more efficient paint stripping method. However these observations have not been substantiated as yet by full, formal process qualification procedures. If such evaluations are pursued it may be demonstrated that enhanced strip rates plus more desirable material effects may be to some degree attributable to the lower mass flow rates.

Production Test Data for the *Jet Stripper* Process

Standoff Distance, inches	Blast Angle, degrees	Water Pressure, psi	Blast Pressure, psi	Media Flow Rate lb/min	Strip Rate ft^2/min	Arc Height, mils	Painted Substrate Material
20	60	3000	60	1.75	0.56	5.43	2024-T3, clad
18	45	3000	60	1.75	0.56	3.32	2024-T3, clad
18	45	3000	60	1.75	0.69	2.90	2024-T3, clad
18	45	3000	60	1.00	0.69	2.55	2024-T3, clad

Tabulated data for WhiteMetal, Inc., Jet Stripper production and Almen data, as developed by SA-ALC. Almen specimens were blasted with the blast direction parallel to the specimen roll direction;. Delta arc heights were measured after 4 blast cycles, and are given as the mean value for three specimens blasted concurrently.

Cladding Erosion Test Data for the *Jet Stripper* Process

Test Specimen	Blast Cycles	Percent Cladding Erosion (assuming 5% cladding thickness)
1	1	22.1
2	2	31.5
3	4	56.4
4	6	72.3

Tabulated cladding erosion data for JET STRIPPER at the following process parameters: 16-inch standoff, 45 degree blast angle, 60 psi blast pressure, 3000 psi water pressure, and 1 lb/min media flow rate. Tests were done with unpainted 2024-T3 clad Almen Specimens.

Appendix III

Acceptance/Integration Test Procedures
and Acceptance/Integration Test Specifications

Sodium Bicarbonate Spray Booth and Associated Equipment

1. Verify Mechanical, Structural, and Installation Details

   A. Booth Size

   B. Doors; 2 - 4' x 7' personnel doors, 1 - 10' x 10' overhead door

   C. Windows; 2 - 3" x 3"

   D. Drain recirculation system

   E. Blast hoses with remote controls; 2

   F. Hose bibs (for wash down)

   G. Sampling drain

   H. Breathing air provisions (4 outlets)

   I. Lighting (100 foot-candles 3' above the floor)

   J. Makeup and exhaust air blower and installation

   K. Pollution control equipment (water wash filtration system)

   L. Installation of booth in assigned area

   M. Utilities installation to booth

   N. Installation of drain pipe in trench

   O. Installation of curbing across shipping room

   P. Installation of partition walls and doors

   Q. Installation of doors in building walls

   R. Electrical hardware and fixtures Class 2 Division

2. Verify Operation of Spray Booth-Related Equipment

   A. Intake and exhaust air flow rates (100 fpm through the booth)

   B. Operation of sump circulating system

   C. Operation of pollution control equipment; i.e., capture of undissolved sodium bicarbonate and mists

   D. Operation of breathing air system

Test Stand, Test Fixture, and
Programmable Specimen Positioning System

1. A. Ability to hold 12" x 24" specimens

   B. Ability to be programmed for movement rate in the 3 to 5 psi range

   C. Ability to hold the sodium bicarbonate blasting nozzle provided by the Government, to establish and maintain standoff distances ranging from 6 to 30 inches between the nozzle discharge point and the specimens, and to establish and maintain an impingement angle ranging from 30 to 90 degrees

   D. Spray protection features

2. Verify Operation of the Specimen Holding System

   A. Install blast nozzle and note standoff distance range and impingement angle range

   B. Install 12" x 24" specimens

   C. Operate XY table and verify travel rates

3. Verify Operation of Accessory Equipment Items

   A. Digital analytical balance readable to a minimum of 0.1 mg

   B. Almen specimen fixture capable of holding 5 Almen strip specimens

   C. Digital Almen specimen arc height gage readable to a minimum of .00001 inch

D. Digital dry film thickness gage capable of measuring coating thickness on a nonferrous substrate, readable to a minimum of .00001 inch

Integration Tests of the Sodium Bicarbonate Spray Booth and the Specimen Holding/Moving Equipment

1. Install the Battelle-provided test stand/test fixture/programmable sample positioning system in the spray booth.

2. Install the Government-provided blasting nozzle on the test stand at a nominal standoff distance and angle.

3. Turn on the blasting equipment and test stand equipment

   A. Determine whether the test stand equipment operates satisfactorily with the nozzle in operation.

   B. Determine whether spray is excluded from the test stand equipment satisfactorily.

APPENDIX IV

APPENDIX V

Appendix VI

JOINT PAINT REMOVAL STUDY
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